

Centrifugal pump without bearings or seals

By combining a canned-motor with a magnetically levitated pump rotor, Switzerland's Levitronix GmbH has achieved a centrifugal pump with neither shaft seals nor rotor bearings. This has many advantages for the handling of a range of sterile, shear-sensitive or delicate fluids. The feasibility of the concept was first demonstrated in 1995 by a group at Sulzer Electronics who went on to establish Levitronix in January 2001 in order to develop and commercialize the technology. CEO Dr Reto Schöb explains the basics of the pump's design and its advantages for a number of medical and industrial applications.

A major problem with centrifugal pumps delivering ultra-pure, highly toxic, sterile or delicate fluids is the shaft seal, which seals the rotating drive shaft against the casing. According to P.C. Barnard from Exxon Chemical Ltd, 80% of the pumps employed in the chemical industry are withdrawn from service because of mechanical seal failures, with the remaining 20% withdrawn as a result of failure of bearings, couplings and other associated items¹. These pumps will have a maintenance cost of approximately twice their value in the first five years of life.

One answer to this problem is magnetic coupling pumps or canned-motor pumps. The latter have a

hermetic casing separating the rotating parts of the pump from the stator. In both cases the torque is transmitted through the canning onto the rotor by means of a rotating magnetic field. In the magnetic coupling pump the rotating field is generated by rotating magnets, in the canned-motor pump by electric stator windings.

A fundamental problem with these hermetically sealed centrifugal pumps is the rotor sleeve bearings, which are lubricated and cooled by the process fluid. These bearings get destroyed immediately if the pump runs dry. Also not all fluids are good lubricants. Fluids with low vapour pressure evaporate in the bearings, and fluids such as CMP (chemical mechanical planarization)

slurries that contain abrasive particles cause fast bearing wear. Biological fluids like blood get destroyed in the bearing and tend to clot. In the semiconductor industry, particles generated by the sleeve bearings can cause problems, and in the plating industry, the plating material tends to deposit in the narrow bearing gap and finally jams the bearing.

Magnetically levitated rotor

All these problems can be addressed by magnetic levitation technology. Prototypes of canned-motor pumps using magnetic bearings have been built and tested by several groups²⁻⁴. None of these pumps has so far become a commercial product because of the high cost associated with magnetic bearings. However, with the revolutionary technology of the so-called bearingless slice motor – developed by the Levitronix group in cooperation with the Federal Institute of Technology (ETH) Zürich – a very simple centrifugal pump with magnetically levitated impeller becomes feasible. The Levitronix design has a single motor/bearing unit that provides drive and magnetic bearing functions at one and the same time, and is capable of stabilizing the six special degrees of freedom of the pump impeller magnetically and without contact through the walls of the pump housing. Compared to conventional canned-motor pumps, much larger magnetic gaps can be realized with the new technology and there is more room for the canning between the rotor and the

Figure 1. Schematic showing the basic principles of the bearingless canned-motor pump.

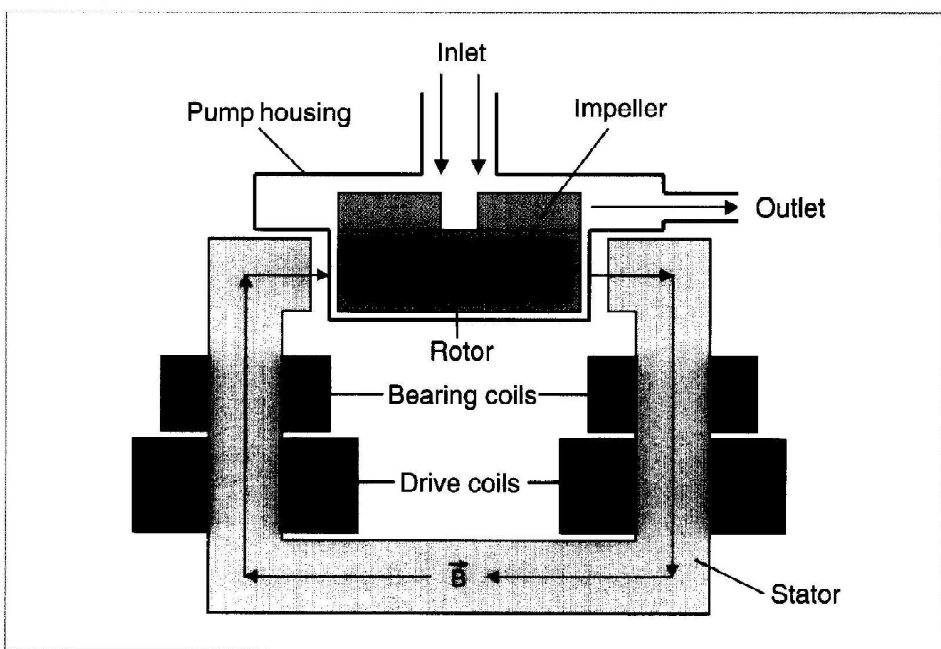




Figure 2. Cross-section through a bearingless canned-motor centrifugal pump (Levitronix BP 3.1).

motor stator. The canning can be made of plastic materials and form a portion of the pump housing. This makes the pump itself a very simple design comprising only three parts: an impeller containing an over-moulded magnet ring, a lower housing and an upper housing (Figures 1 and 2). The pump component can be simply detached from the motor/bearing stator enabling it to be cleaned very easily. For certain applications, such as for blood pumps, the pump can be produced as a disposable item (Figure 3).

Outstanding features

Due to its unique construction, the Levitronix bearingless canned-motor pump has several outstanding features. Simply put it combines all the advantages of conventional canned-motor or magnetic coupling pumps but avoids the problems related to the process-lubricated bearings. There are no narrow gaps and fissures and the pumps do not generate any particles. They can be operated even with such critical fluids as blood or ultra-pure chemicals and CMP slurries. Because there is no mechanical coupling of the impeller and the pump casing, the pump produces virtually no vibrations,

even if there is a huge imbalance in the impeller (for example, if solid parts are stuck in an impeller). Thus, the bearingless pumps are very quiet; only at high flows can turbulence-induced noise be heard. The absence of any

mechanical contact between rotating and stationary parts leads to a virtually wear-free product. The pump part may wear with time if operated with abrasive fluids or very aggressive chemicals, but if this happens it can be exchanged very easily within a few seconds or minutes, depending on the type of mountings and fittings.

In addition, due to its variable speed, the Levitronix pump allows precise control of flow or pressure and a wide operating range. With just one pump model, a whole range of conventional fixed frequency pumps can be replaced. Due to its avoidance of bearings and metal cans, and because of the wide gaps and small motor surfaces, very high operating speeds (up to 10 000 rpm) are possible. Therefore high pressures can be achieved with only one stage. As an example, 6 bar (87 psi) is feasible with an impeller diameter of only 65 mm. This also allows the pumps to be built smaller than fixed-speed pumps of the same power.

The benefits of the Levitronix pump can be divided into three categories – those dependent on the canned-motor design, those stemming from the

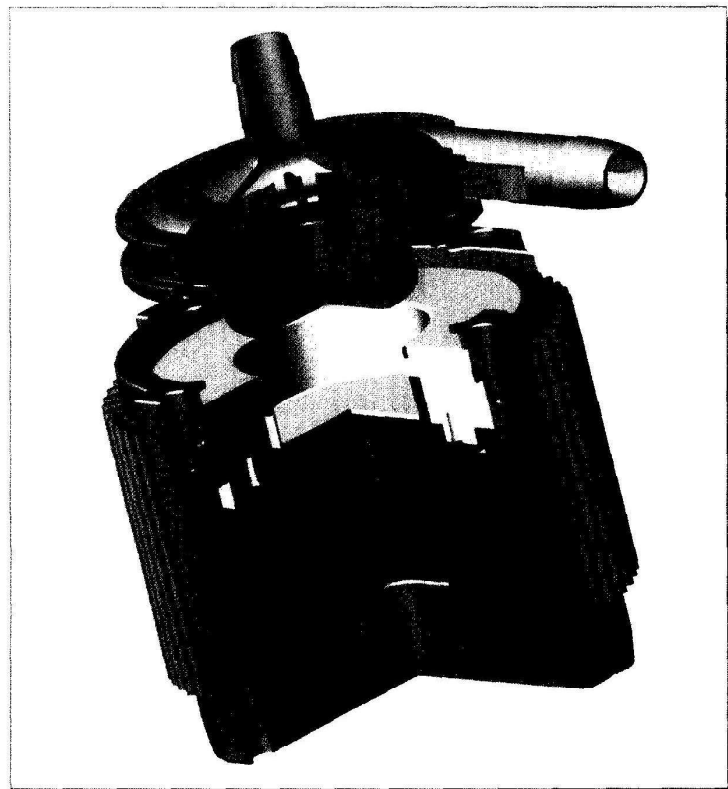
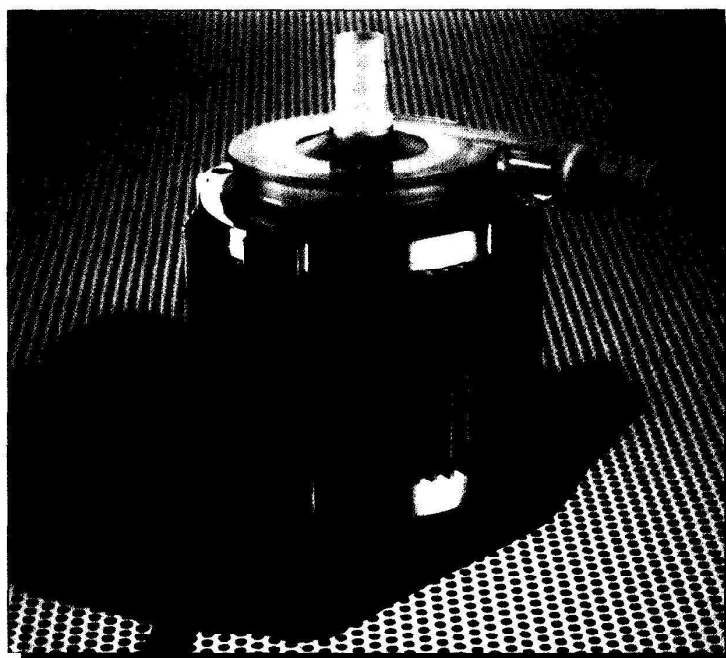


Figure 3. Design of a bearingless canned-motor pump with disposable pump.

Figure 4. A bearingless blood pump system designed for extracorporeal circulatory support and featuring a disposable polycarbonate pump.



magnetic levitation of the impeller, and those due to the electronic speed control – and are summarized below.

Canned-motor design

- No rotating seals → self-contained system

Magnetic levitation of the impeller

- No wear → reduced downtime and low maintenance cost
- No lubrication required →

capability for dry running

- No particle generation
- No narrow clearances and fissures → no clotting, simple cleaning and sterilization
- Simple cleaning and exchange of the pump component
- Wide temperature range
- Extremely low vibration and size

Electronic speed control

- Precise control of flow rate or pressure

- Flow control without throttle valves → high system efficiency
- Continuous or pulsating flow by control
- High pressure from a single-stage pump
- Small size compared to diaphragm and bellows pumps

Current limitations

The main limitation of the bearingless canned-motor pump today is its high price, which is comparable to bellows and diaphragm pumps of similar size and materials. This limits the current range of applications to the most demanding ones. Another current constraint is the choice of materials (plastics) and the size (smaller than 500 W). The feasibility of metal pumps and larger systems has already been shown in the lab, so the last two constraints are only temporary.

Applications

Medical applications

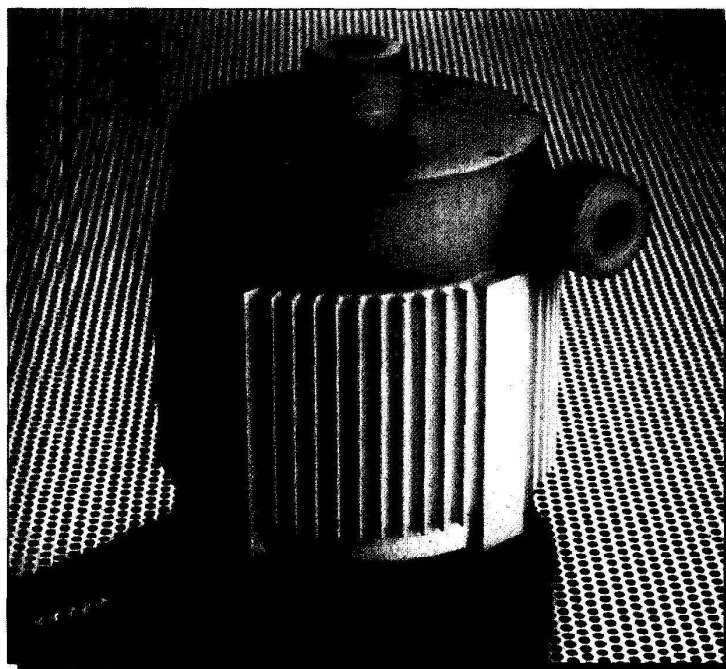
The first pump was designed for medical applications (Figure 4). It consists of a small motor/bearing unit (DxH ≈ 87 x 70 mm) and a disposable polycarbonate pump. It can deliver flow rates of up to 18 litres (4.7 gallons) per minute and pressures of up to 1.1 bar. The pump was specially designed for pumping blood in extracorporeal circulatory support applications (cardiopulmonary bypass). Due to its low shear design, the haemolysis rate of this pump is about half that of today's 'gold-standard' pump for this application, the Biomedicus BP-80 from Medtronic.

Because of the wide blood-gaps and the absence of stagnation zones, the bearingless pump is also non-thrombotic and can be operated with blood over an extended period of time without clotting. Clearance from the FDA is anticipated later this year.

Semiconductor industry

The same properties of low shear and prevention of coagulation are also essential for pumping CMP slurries and for gold plating during chip manufacturing. The absence of particle generation, precise continuous flow,

Figure 5. Bearingless canned-motor pump for the semiconductor industry with a high purity PVDF pump and chemically resistant motor housing (ECTFE coated).



and chemical inertness are additional requirements in the semiconductor industry. A bearingless pump system with high-purity PVDF or PTFE pump heads has been especially designed for this demanding industry (Figure 5). It can deliver flows of up to 50 litres per minute and pressures of up to 2.5 bar. For more than a year this pump has been successfully used in etching, cleaning and stripping processes during chip production at semiconductor facilities in Europe, Asia and the USA. Smaller as well as larger models (up to 120 l/min and 6 bar) with PTFE pump heads are currently being tested in the lab.

Biotechnology

A Levitronix pump has no fissures or small gaps where bacteria could survive during sterilization. In combination with the leak-free design, this makes it an ideal pump for biochemical applications. It allows the design of completely hermetic bio-production systems. With a special flange and impeller, the pump can also be used as a sealless, bearingless stirrer. The pulse-free, continuous flow makes it an ideal choice for cross-flow filtration systems.

Plating industry

Metal solutions and paints tend to coagulate in process-lubricated bearings and some of them are also sensitive to high shear. Presumably, the wide-gap, low-shear, hermetic design of the Levitronix pump would help to solve these problems. The pump is therefore currently being evaluated in several plating applications.

Summary and outlook

The bearingless canned-motor pump combines all the advantages of conventional canned-motor or magnetic coupling pumps but avoids the problems related to process-lubricated bearings. Initial products have been designed for the medical and semiconductor industries. Other applications in the biotechnology and plating industry are currently under evaluation. Further developments will lead to larger pumps and the use of other materials. In addition, the high cost will come down as larger quantities are produced and electronics costs fall. This might open the way to much wider applications for these pumps in the chemical and food industries. ■

References

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